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NASA HIGH TEMPERATURE LOADS CALIBRATION LABORATORY

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Edwards, Calif.

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16. Abstract

The NASA High Temperature Loads Calibration Laboratory and the equipment it contains for simulating the loading and heating of aircraft or their components are described. Particular emphasis is placed on various fail-safe devices which are built into the equipment to minimize the possibility of damage to flight vehicles. The data-acquisition system is described. This system involves on-site pickup of data and signal conditioning coupled with conversion from analog to digital data and transmission to a central area for recording on magnetic tape and distribution to real-time displays. Instrumentation available in the facility for measuring load, position, and strain is also discussed.

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INTRODUCTION

The requirement to measure flight loads on aircraft flying at supersonic and hypersonic speeds led to the construction of a laboratory for calibrating strain-gage installations to measure loads in an elevated temperature environment. The problems involved in measuring loads with strain gages (ref. 1) require the capability to heat and load aircraft under simulated flight conditions.

This paper describes the NASA High Temperature Loads Calibration Laboratory at the Flight Research Center, Edwards, Calif. The laboratory has the capability of testing structural components and complete vehicles under the combined effects of loads and temperatures, and calibrating and evaluating flight loads instrumentation under conditions expected in flight. The laboratory provides close support of flight-to-flight program planning by structural-integrity testing, instrumentation calibrations, and analysis of unexpected problems encountered in the course of exploratory flights.

GENERAL DESCRIPTION

The laboratory is a hangar-type structure with a small shop and office area attached to one end to accommodate the operations staff. It is located adjacent to Rogers Dry Lake and is connected to the dry lake and the Edwards Air Force Base runways by a ramp and taxiway as shown in figure 1.

Hangar Test Area

Figure 2 is a sketch of the building layout. The hangar-door opening is 40 feet (12.2 meters) high and 136 feet (41.6 meters) wide. Additional access to the test area from the exterior is provided by personnel doors and an equipment door. Access to the test area from the shop area is provided by two equipment doors. The unobstructed test area is 150 feet (45.7 meters) long by 120 feet (36.6 meters) wide by 40 feet (12.2 meters) high. There are 16 tiedown slots spaced 6 feet (1.8 meters) apart, 7 instrument wire trenches, 7 electrical power trenches, and 5 mechanical trenches.

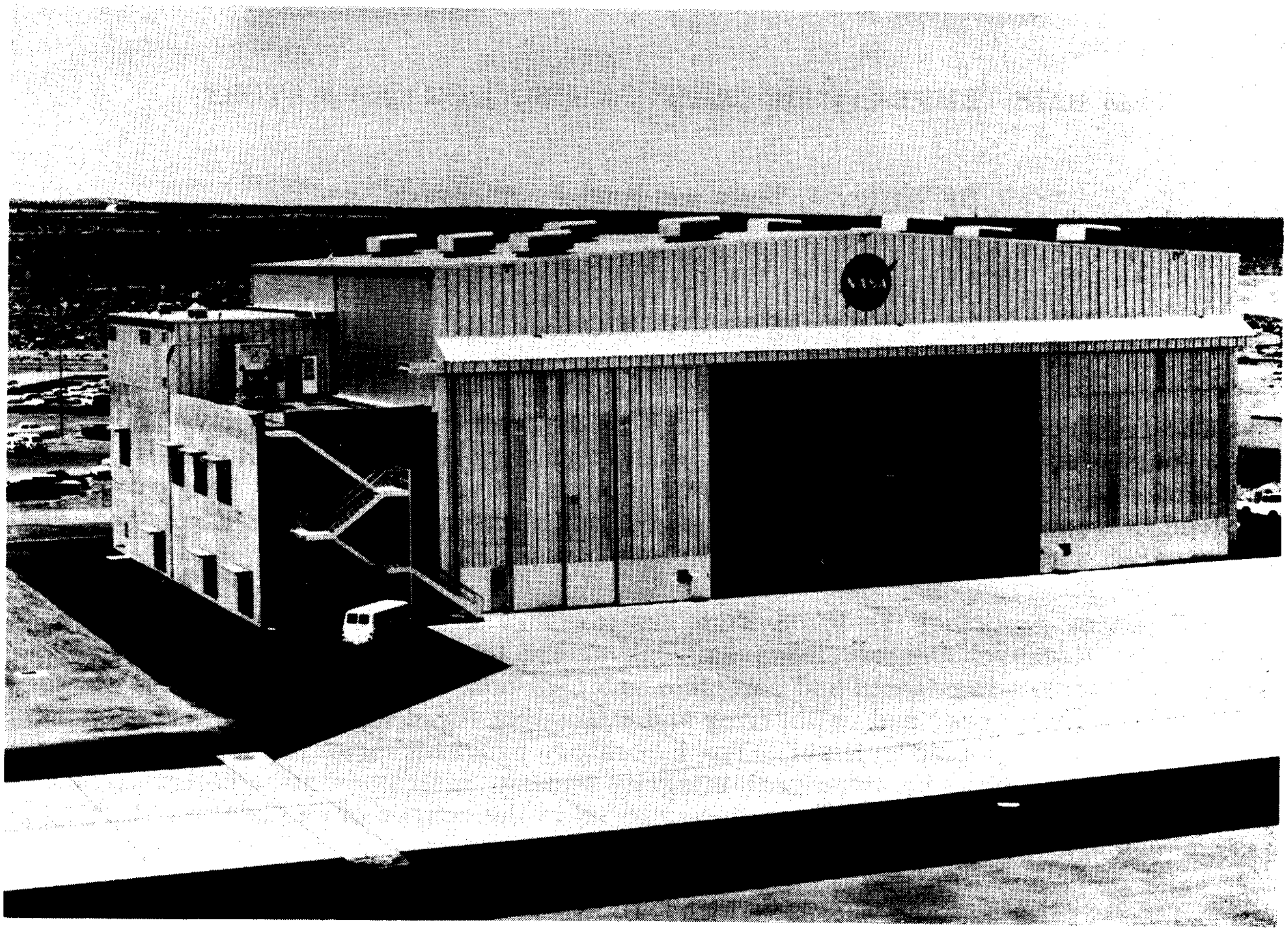


Figure 1.–Front view of NASA High Temperature Loads Calibration Laboratory.

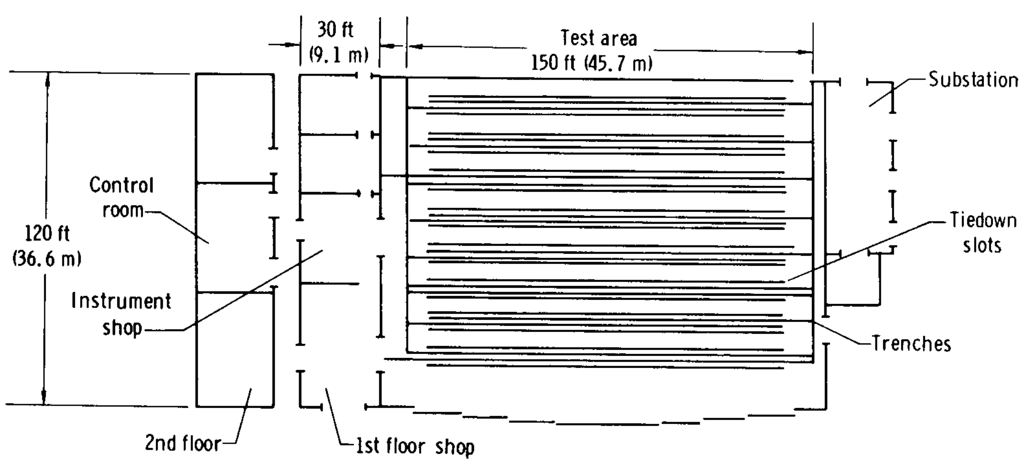


Figure 2.–Building layout of NASA High Temperature Loads Calibration Laboratory.

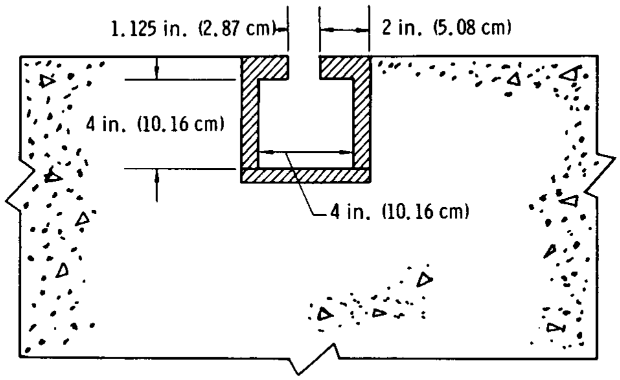
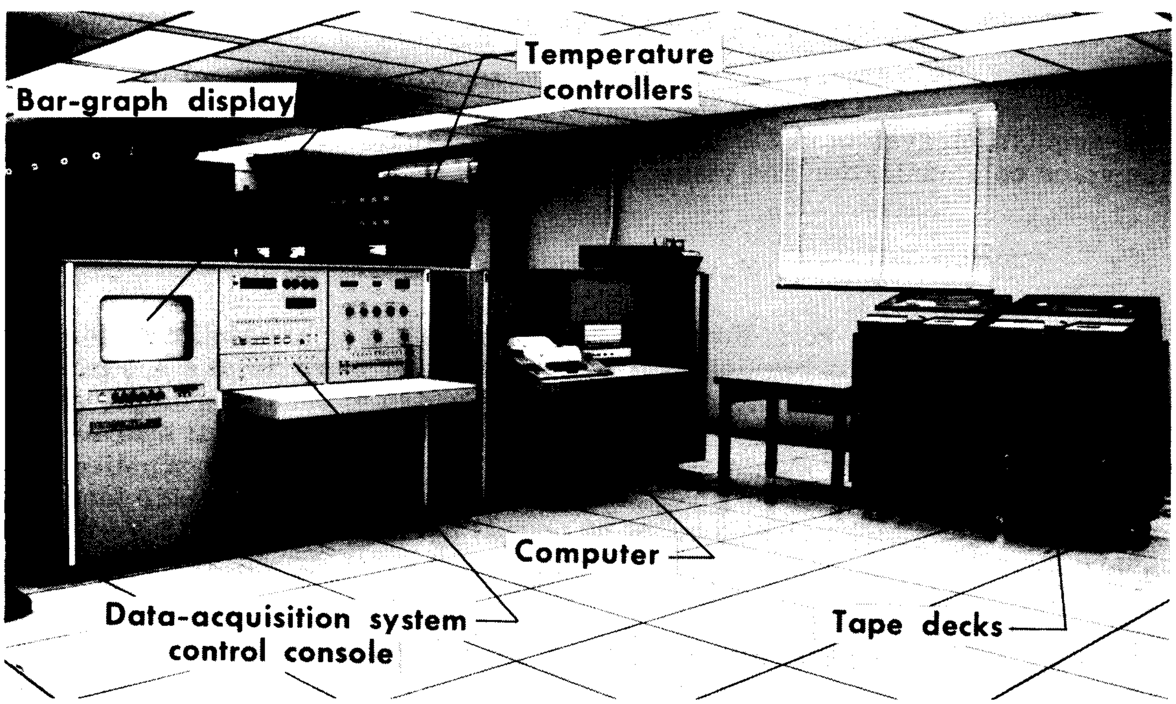


Figure 3.–Cross section of typical tiedown slot.

The cross-sectional dimensions of the trenches are 10 inches (25.4 centimeters) by 12 inches (30.5 centimeters). The mechanical trenches distribute hydraulic power, water, and compressed air to the test area. The maximum load capability of the tiedown slots is 15,000 pounds (67,000 newtons) uplift every 2 feet (0.6 meter). Figure 3 shows a sketch of a typical tiedown slot. A 5-ton (44,000-newton) overhead crane services the entire hangar test area.

Control Room

The control room for the heating equipment, loading equipment, and data-acquisition system is on the second floor (figs. 2 and 4). Two observation windows, 11 feet (3.4 meters) wide by 4 feet (1.2 meters) high, and a closed-circuit television system are provided for monitoring the test area. The television system has several cameras which can be positioned in the hangar test area; one can be controlled remotely from the



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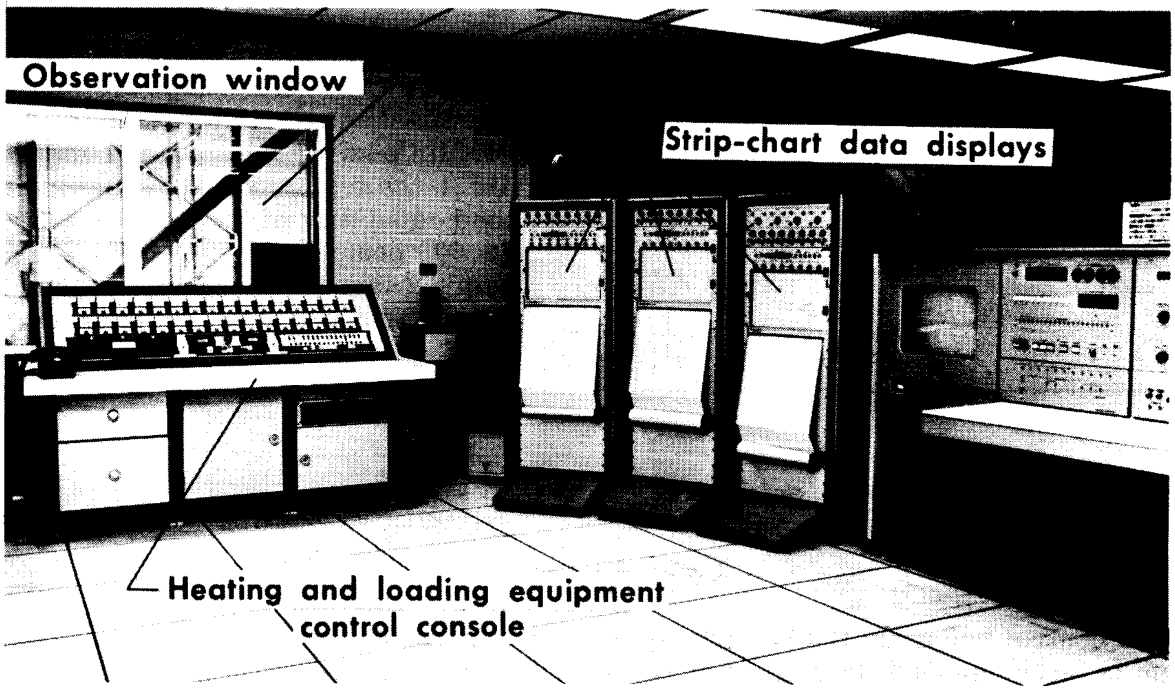
(a) Acquisition and control equipment.

Figure 4.–NASA High Temperature Loads Calibration Laboratory control room.



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(b) Master control and display area.

Figure 4.– Concluded.

control room for tilt, pan, elevation, focus, and zoom. A two-channel intercommunication system is provided between the control room and the eight acquisition sites of the data-acquisition system in the hangar test area. Audio and video tape machines provide voice communication and visual recording of the test.

Power Distribution

Ten megawatts of 480-volt, three-phase, 60-cycle power are available for distribution to 103 ignitron power regulators. Hydraulic power consists of a 4.5 gallon per minute (284 cubic centimeter per second) supply operated at 3000 pounds per square inch (20.7 meganewtons per square meter). As the need for additional hydraulic power becomes apparent, a larger supply will be added. Compressed air is supplied by a 125-horsepower (93,250-watt) compressor capable of delivering 845 cubic feet per minute (0.398 cubic meter per second) at 60 pounds per square inch (413.7 kilonewtons per square meter).

EQUIPMENT CONFIGURATION AND CAPABILITIES

Hydraulic and Thermal Load Control Systems

Figure 5 is a block diagram of the hydraulic and thermal load control systems. These systems have the capability of loading and heating test specimens simultaneously by following programs of load and temperature. The hydraulic and thermal load control systems are programed by the same type of function generator and by similar controllers. Both the function generators and the hydraulic and thermal load controllers described in this section are analog devices. A digital system for programing and control which is being implemented is discussed in the section entitled DATA-ACQUISITION AND CONTROL-SYSTEM EXPANSION.

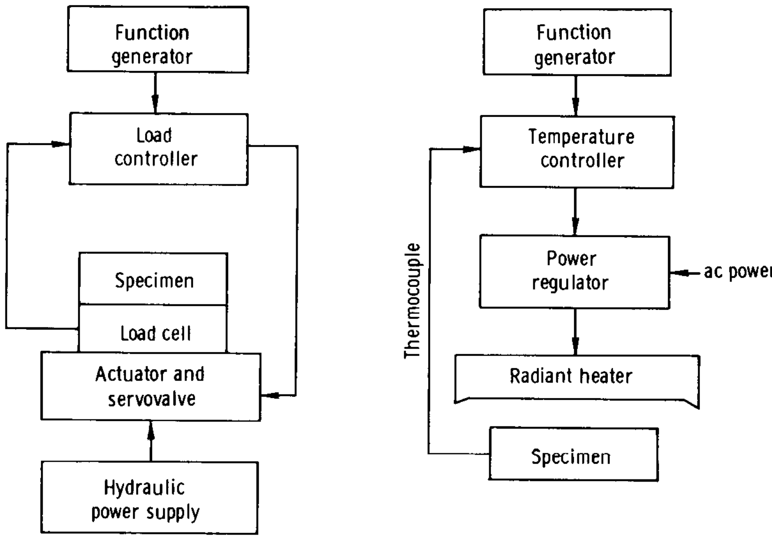

Figure 5.–Block diagrams of hydraulic and thermal load control systems.

The function generator, as used for loading, is a device that enables the engineer to program the load applied to a specimen as a function of time. This is accomplished by plotting the desired load time history on a metalized sheet of graph paper, attaching the graph to a drum, and inserting the drum into the function generator. After the system is energized, the drum turns and a servo-controlled probe follows the curve, driving an actuator as required to maintain the load called for by the graph. The actuator loads the test specimen through a load cell which feeds a signal back to the load controller, thus completing the servo loop. In a similar way, temperature is programed by the function generator driving a temperature controller which varies the voltage level to the lamps as required to maintain the temperature called for by the graph. A thermocouple at the control point feeds a signal back to the temperature controller to complete the servo loop.

The function generators used are adjustable to provide time bases from 2.400 inches per hour (1.693 centimeters per second) to 3.75 inches per hour (0.00265 centimeter per second) with an accuracy and repeatability within 1 percent of elapsed time. The performance characteristics of the function generators are as follows:

1. Maximum probe-following rate is 7 inches per second (17.7 centimeters per second).
2. Static positional accuracy and repeatability of the probe is 0.1 percent of full scale.
3. Dynamic positional accuracy of the probe is 1.0 percent at maximum probe-following rate.

Hydraulic Loading System

The hydraulic loading system consists of 14 channels of closed-loop load or position control with 14 function generators of the type described in the preceding section. Thirty-four electrohydraulic actuators are available for use with the system. The configuration and physical characteristics of the hydraulic actuators are presented in table I. Hydraulic power is supplied to the actuators through a flexible high-pressure hose which connects the actuator to hydraulic pressure and return lines located in the floor trenches.

The hydraulic loading system has fail-safe provisions, as shown in figure 6. A first precaution is to limit the hydraulic pressure to permit the actuator to apply only the required load. A second protective device is a limit switch which can be set to trip at any prescribed deflection. Tripping a limit switch can cause one of three preselected events to occur: (1) indicate only, (2) lock, or (3) lock and dump. When the system is locked, the two lock valves shown in figure 6 close and stop all flow of hydraulic fluid in and out of the actuator, thereby preventing all movement of the actuators, and the applied load remains as it was before the system was locked. For a lock and dump situation, the lock valves close (preventing flow into the actuator) and the dump valves open (releasing pressure from both sides of the actuator), relieving the applied load. A third device is an error-detection system which senses the error between feedback and command. If the error exceeds a predetermined amount, the system will cause one of the three preselected events mentioned previously to occur: indicate only, lock, or lock and dump. A fourth protection is an alarm system, which is described in the Data-Acquisition System section.

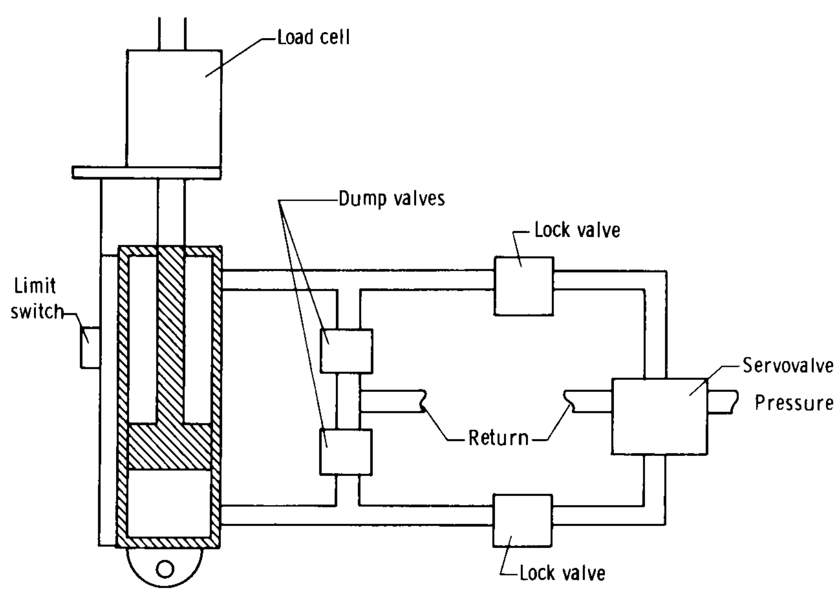

Figure 6.–Electrohydraulic fail-safe system.

Two manually operated air-hydraulic pumps are also available for manual loading of structures with hydraulic jacks. The capacity of each jack is approximately 8,000 pounds (35.6 kilonewtons).

Thermal Loading System

The available programed heating equipment consists of 103 power control channels capable of regulating 10 megawatts of power continuously. Significant overloads can be tolerated for short periods of time. Ninety-six channels have a power capability of 100 kilowatts per channel and can be programed from 32 function generators. Seven channels are portable units and can be used wherever 480-volt power is available; four of these channels have a capability of 200 kilowatts per channel. Electrical power is permanently connected to the power control channels from the transformers with bus bars. Connection of electrical power to the lamps is by flexible cable with high-temperature insulation. Cables to the lamps are routed through floor trenches.

At present, the primary protective or fail-safe capability used with the heating equipment is a voltage-limiting system which enables the operator to limit the voltage applied to the heat lamps for each channel control. To use this system effectively it is necessary to know the amount of power needed to achieve the heating rates and temperature levels required by the tests. Once this information is known, it is necessary to limit the power applied to each channel to avoid exceeding these values.

Heat is applied to the specimen through the use of infrared quartz lamps which are available in various lengths from a 5-inch (12.7-centimeter) lighted length to a 32-inch (81.3-centimeter) lighted length. Reflector arrangements are readily adaptable to individual requirements for heating rates in the range of 0 to 100 Btu/ft^2-sec (1.13 MW/m^2) and temperatures up to 3000° F (1922° K). A typical heating test is described in reference 2.

Data-Acquisition System

The usefulness of tests depends upon the amount and accuracy of the data acquired from them. Consequently, a great deal of emphasis has been placed upon the data-acquisition system. The system is described in detail in reference 3, and a block diagram is presented in figure 7.

The instruments whose outputs are to be recorded are connected to acquisition "sites" near the test setup. Each acquisition site can accommodate up to 40 strain-gage channels, 50 thermocouple channels, and 10 position-sensor channels. Eight acquisition sites are available, so that the system can handle up to 320 strain gages, 400 thermocouples, and 80 position transducers. The sites contain signal conditioning and strain-gage-bridge balancing equipment. They also convert data from analog to digital form for transmission to the control room. This configuration minimizes effects of electrical noise generated by the thermal loading system. Each site has its own air-conditioning unit to improve the reliability of its performance in the changing thermal environment.

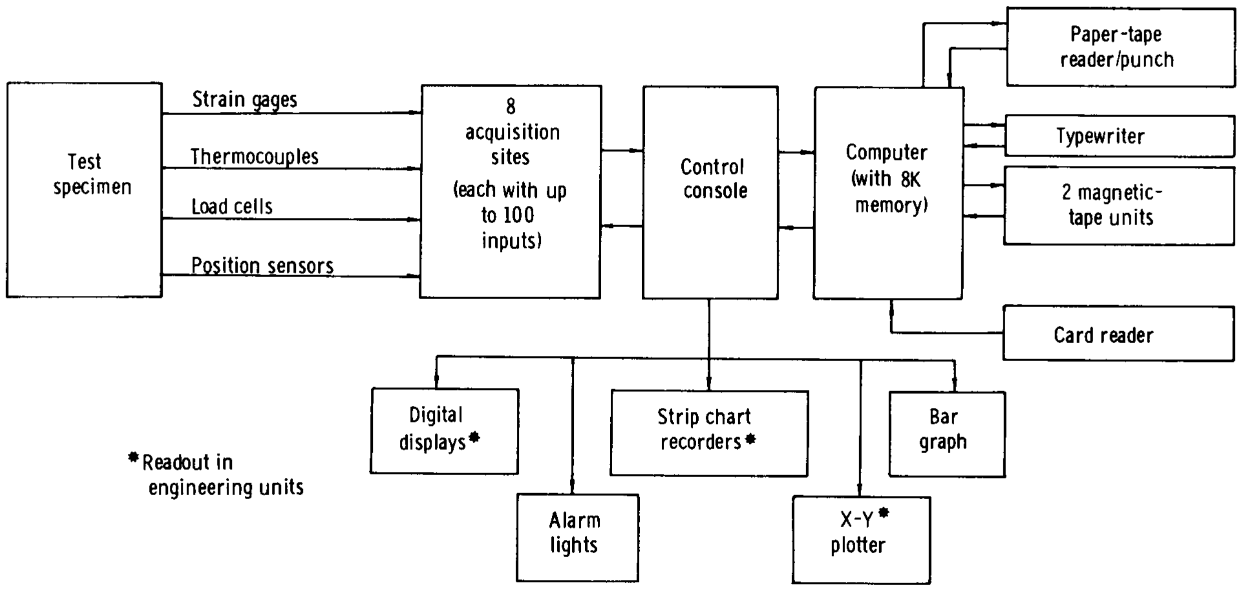

Figure 7.–Block diagram of data-acquisition system.

The data acquired by the acquisition sites are routed to the control console, which is the interface between the test conductor and the data-acquisition system. The console contains a number of displays which keep the test conductor informed about the progress of the test. The control console, in turn, communicates with a high-speed digital computer which acts as a command and control device for the data-acquisition system. Under stored program control, it commands the channel sampling sequence and the sensitivity at which each channel is measured. Data are formatted in the computer for output magnetic-tape units. Information is recorded on magnetic tape in IBM 360 9-track format. Data are reduced on the NASA Flight Research Center System 360 general-purpose computer.

Numeric displays of test time and data from any one channel (reduced to engineering units if desired) and a bar graph displaying analog lines whose lengths are proportional to data from any 32 selected channels are available at the control console. Also, three strip-chart recorders are connected to the control console to provide quick-look analog time histories of up to 24 channels of information. If desired, an X-Y plotter can be connected to two strip-chart channels to produce, in real time, a plot of one variable versus another. Twenty alarm lights are available to indicate noteworthy or hazardous conditions. The lights can also be used for automatic test shutdown. To observe the test, the test conductor sits in front of a large window overlooking the test area (see fig. 4). For more detailed, close-up viewing, closed-circuit television is provided. The control room, which is remote from the test area, can be connected by an intercommunication system to any acquisition site.

Instrumentation

The transducers available for use in the facility include strain gages, thermocouples, load cells, and position transducers.

A strain-gage laboratory within the facility provides the capability for installing and testing strain gages under environmental conditions of heat and load. Various types of strain gages, including those requiring welded and flame-spray attachments, can be installed. Thermocouples can also be installed in the strain-gage laboratory. The thermocouples used are typically spot-welded chromel-alumel.

The configuration and physical characteristics of the load cells available in the facility are presented in table II.

Six standard self-contained aircraft weighing kits are available with the following capacities:

Capacity per cell		Number of cells	Quantity	Accuracy
lb	(N)			
10,000	(44,482)	3	3	±0.1 percent of reading or ±2 lb (±8.9 N)
25,000	(111,205)	4	2	±0.1 percent of reading or ±5 lb (±22.2 N)
50,000	(222,411)	3	1	±0.1 percent of reading or ±20 lb (88.90 N)

Forty-eight potentiometric displacement transducers are available with the following specifications:

Range		Resolution		Cable tension		Quantity
in.	cm	in.	mm	oz	N	
0 to 1	0 to 2.54	±0.002	0.05	9	2.5	4
0 to 6	0 to 15.24	±.011	.28	9	2.5	14
0 to 12	0 to 30.48	±.022	.56	9	2.5	12
0 to 12[a]	0 to 30.48	±.017	.43	19	5.3	4
0 to 24	0 to 60.96	±.042	1.07	14	3.9	14

[a]This transducer has a separable cable which permits the cable to release when its range is exceeded without damage to the component parts.

Twenty-four dial-gage displacement-measuring devices are also available with ranges varying from 3/8 inch (0.95 centimeter) to 4 inches (10.16 centimeters).

DATA-ACQUISITION AND CONTROL-SYSTEM EXPANSION

An expansion program is in progress at the NASA High Temperature Loads Calibration Facility. The expansion will not alter the available test area, but will significantly increase the capability for simulating thermal environments on large test specimens.

The number of temperature control channels will be increased to approximately 500. Each new channel will be capable of controlling up to 50 kilowatts of electrical power, with a total of 20 megawatts available for a single test.

Along with the increase in available power control channels, the control philosophy will be changed. The system will be converted from analog control to direct digital control, with each channel capable of being independently programed for temperature. The system is designed to be further expanded if the need should arise.

The data-acquisition capability will be increased from 800 to 1200 measurement channels, with further increases possible if required.

CONCLUDING REMARKS

The NASA High Temperature Loads Calibration Laboratory provides the capability for both loading and heating flight structures under controlled conditions and simultaneously acquiring data from a large number of sensors. It is particularly suited for installing and calibrating strain-gage installations for in-flight structural-loads measurements and for the application of structural proof-test loads in support of flight safety when the simulation of aerodynamic heating is required.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., May 23, 1969.

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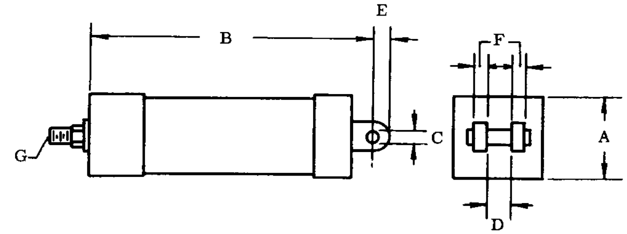
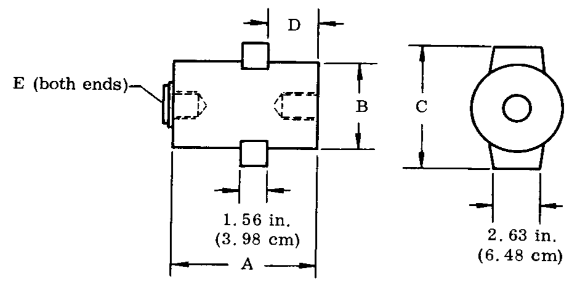
3. Wright, H. Vernon: Airframe Environmental Computer-Controlled Data Acquisition System. Proceedings of Thirteenth National ISA Aerospace Instrumentation Symposium, June 1967, pp. 369-383.

TABLE I. – HYDRAULIC-ACTUATOR CONFIGURATION AND PHYSICAL CHARACTERISTICS



Bore		Rod diameter		Piston area				Dimensions												Thread, G	Stroke		Quantity
				Tension		Compression		A		B		C		D		E		F					
in.	cm	in.	cm	in.^{2}	cm^2	in.^{2}	cm^2	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm	in.	cm		in.	cm	
1.50	3.81	0.750	1.90	1.326	8.581	1.767	11.400	2.5	6.35	13.25	33.65	0.50	1.27	0.75	1.91	0.50	1.27	0.50	1.27	1/2-20NF	6	15.24	2
1.50	3.81	.625	1.59	1.460	9.419	1.767	11.400	2.5	6.35	12.75	32.39	.50	1.27	.75	1.91	.50	1.27	.50	1.27	1/2-20NF	6	15.24	4
1.50	3.81	.625	1.59	1.460	9.419	1.767	11.400	2.5	6.35	20.25	51.44	.50	1.27	.75	1.91	.50	1.27	.50	1.27	1/2-20NF	12	30.48	6
2.00	5.08	1.375	3.49	1.660	10.710	3.142	20.271	3.0	7.62	36.50	92.71	.75	1.91	1.25	3.18	.75	1.91	.63	1.60	1-14NF	24	60.96	4
2.50	6.35	1.386	3.52	3.400	21.935	4.909	37.671	3.5	8.89	27.63	70.18	.75	1.91	1.25	3.18	.75	1.91	.63	1.60	1-14NF	18	45.74	4
2.50	6.35	1.750	4.44	2.410	15.548	4.909	37.671	3.5	8.89	36.63	93.04	.75	1.91	1.25	3.18	.75	1.91	.63	1.60	1-14NF	24	60.96	2
2.50	6.35	1.785	4.56	2.500	16.129	4.909	37.671	3.5	8.89	36.63	93.04	.75	1.91	1.25	3.18	.75	1.91	.63	1.60	1-14NF	24	60.96	2
3.25	8.26	2.000	5.08	5.160	33.290	8.292	53.522	4.5	11.43	37.50	95.25	1.00	2.54	1.50	3.81	1.00	2.54	.75	1.91	1-14NF	24	60.96	4
4.00	10.16	2.000	5.08	9.420	60.774	12.560	81.032	5.0	12.70	35.70	90.83	1.38	3.51	2.00	5.08	1.38	3.51	1.00	2.54	1 1/2-12NF	24	60.96	6

TABLE II. – LOAD-CELL CONFIGURATION AND PHYSICAL CHARACTERISTICS



Capacity		Dimensions								Thread, E	Quantity	Accuracy percent of full scale
		A		B		C		D				
lb	N	in.	cm	in.	cm	in.	cm	in.	cm			
500	2,224	4.56	11.58	3.50	8.89	5.63	14.30	1.25	3.18	1/2-20NF	1	0.25
2,000	8,896	4.56	11.58	3.50	8.89	5.63	14.30	1.25	3.18	1/2-20NF	4	
5,000	22,241	5.94	15.09	3.50	8.89	5.63	14.30	1.81	4.60	1-14NF	6	
10,000	44,482	5.94	15.09	3.50	8.89	5.63	14.30	1.81	4.60	1-14NF	4	
20,000	88.964	8.50	21.59	5.00	12.70	6.94	17.63	2.81	7.13	1 1/2-12NF	6	